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Design of a New Wideband Microstrip Filtering Antenna Using PCML-SIR Technique

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Abstract

This article proposes a new design structure of a wideband Microstrip filtering antenna. The design structure of Microstrip filtering antenna is based on the integration of Parallel Coupled Microstrip Line Stepped Impedance Resonator (PCML - SIR) filter with the Monopole patch antenna. The proposed filtering antenna is suitable for high-speed data rate transmission applications, which has a center frequency $f_o = 5.76\ GHz$. The planned structure has a Fractional Bandwidth (FBW) of about 20 %, a return loss ($R_L = -19\ dB$) and a gain over the passband frequency equals to (2.88 dB). The proposed microstrip filtering antenna has a good radiation efficiency of about (71.67 %). This design has an incomplete ground plane and a reversed L-shaped slit loaded. The proposed filtering antenna design was simulated using Computer Simulation Technology (CST) Studio Suite software. The design shows a good agreement matching between the PCML-SIR filter and the monopole patch antenna. The simulation design results showed a low loss in the passband and high suppression of the spurious responses in the stopband. The main goal of the PCML-SIR design is to use for high-speed data transmission, which needs to spread frequency spectrum.

Keywords: filtering antenna, a Monopole patch antenna, PCML – SIR filter, WLAN applications, Computer Simulation Technology (CST), spurious responses

1. Introduction

Multipurpose, multifunction of the components of the suggested design of a compact size are extremely desirable in modern communication systems [1]. Filters and antennas have played a major role in communication systems. They characterized the key components for most microwave circuits. The antenna transmits and receives simultaneously (transceiver) electromagnetic waves while the bandpass filter (BPF) passes signals in the passband and rejects spurious signals (out-of-band) [2]. The great need for communication systems led to the design of small size and low cost of transmitting and receiving microwave devices. One of the design techniques presently used is to integrate different parts of components into a single module such that fewer components are to be used [3]. Simply, the circuit theory guides the researchers to the need for multiple coupled resonances to realize the passband and stopband filtering effect of the two specific terminals. Synthesize any filtering function depends on the form of the resonances and their mutual associations. Based on its simplicity and mathematical rigorousness, the knowledge is applied from the circuit techniques to the antenna evolution process. Hence, most of the circuit-inspired designs are operative by bringing two resonances simultaneously. This technique provides an opportunity to increase the operation band, also to increase the gain in some cases [4]. Microstrip Monopole patch antennas (MPAs) have proved a satisfactory solution for the antenna designers and researchers interested in this field, especially in areas like antennas for mobile communication base stations and antennas for handsets. The relative bandwidth for mobile communication systems such as Global System for Mobile Communication (GSM) is about 10%. The microstrip patch antenna has an inherent narrow bandwidth. Thus, over the last decade, various techniques have been presented to enhance its passband response e.g., capacitive compensation, thicker substrates, reactive matching networks, stacked patches [5]. Stepped Impedance Resonator (SIR) joined with Parallel Coupled Microstrip Lines (PCML) structure is appropriate for the filter design because the higher-order resonant modes can be shifted or suppressed, and the second passband of the dual-passband response can be created by using the spurious frequency responses [6]. By adjusting the physical dimensions of the central microstrip resonator and PCML – SIRs, the insertion loss, return loss, harmonic suppression, and bandwidth of the filtering antenna design have been made better [7].

This paper presents a new wideband microstrip filtering antenna design that has an incomplete ground plane and reversed L-shaped slit loaded. The design bases on the integration of the Parallel Coupled Lines Stepped Impedance Resonator (PCML-SIR) filter with the (MPA), as shown in Figure 1. The proposed filtering antenna has a relatively wide frequency passband of about 1.16 GHz;

therefore, it is suitable for high-speed data rate transmission applications. This type of data transmission needs a high-frequency spectrum. Consequently, it is used in networks that require high-speed data processing. This structure has a Fractional Bandwidth (FBW =20 %) with a center frequency $f_o = 5.76$ GHz.

2. Rectangular Patch Antenna Design

The rectangular patch antenna (PA) design structure is illustrated in Figure 1. The design equations of the rectangular microstrip (PA) are calculated as shown below [8, 9]:

$$W_p = \frac{c}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \quad (1)$$

c is a light velocity;

ϵ_r is the dielectric constant of the substrate material;

f_r is the resonant frequency of the patch antenna.

W_P is the width of the monopole patch antenna.

$$\epsilon_{reff} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12\frac{h}{W}}}\right) \quad (2)$$

ϵ_{reff} is the effective dielectric constant of the substrate material.

h is the thickness of dielectric substrate material.

W is the width of the dielectric substrate material.

If the thickness of the substrate material h =1.572 mm, the additional length of the dielectric material (ΔL) is given as:

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\epsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (3)$$

The actual length of the dielectric material (L_p) can be calculated as:

$$L_p = \frac{c}{2f_r\sqrt{\epsilon_{reff}}} - \Delta L \quad (4)$$

The dimensions of the length (L_g) and the width (W_g) of the ground plane are given as [10]:

$$W_g = 6h + W \tag{5}$$

$$L_g = 6h + l \tag{6}$$

The optimal physical dimensions of the rectangular patch antenna are stated in Table 1. Figures 2 and 3 show the simulated results of the S_{11}-parameter and the 3D –view of the radiation pattern of the conventional patch antenna.

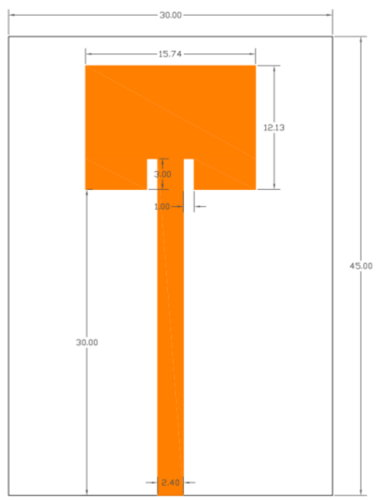


Figure 1 The rectangular patch antenna.

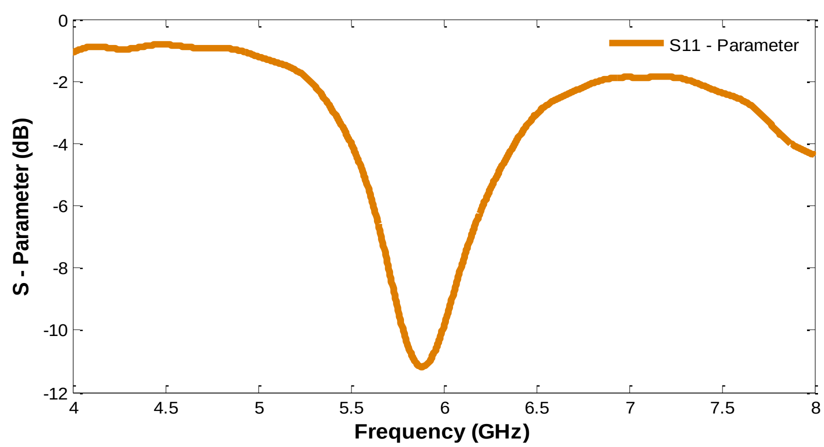


Figure 2 Simulated S_{11}- parameter of the patch antenna design structure.

Table 1 The optimized dimensions of the rectangular patch antenna design.

W (mm)	**L (mm)**	**Wp (mm)**	**Lp (mm)**
30	45	15.74	12.13
Ws (mm)	Ls (mm)	Lm (mm)	Wm (mm)
1	3	30	2.4

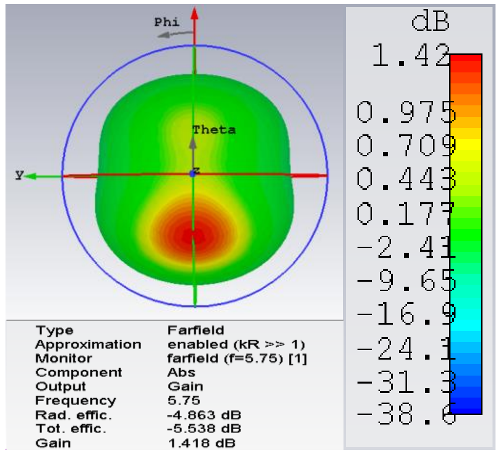


Figure 3 The simulated radiation pattern of the rectangular patch antenna

The single stage of the PCML – SIR structure is illustrated in Figure 4. Deriving the two-port admittance *(Y)* matrix is allowed by the even and odd modes characteristic impedances (Z_{even} and Z_{odd}), respectively, phase constants of even and odd modes (β_{even} *and* β_{odd}), and the lengths of the PCML-SIR of even and odd modes (l_{even} *and* l_{odd}) [11], as shown in Equations (7), (8), and (9):

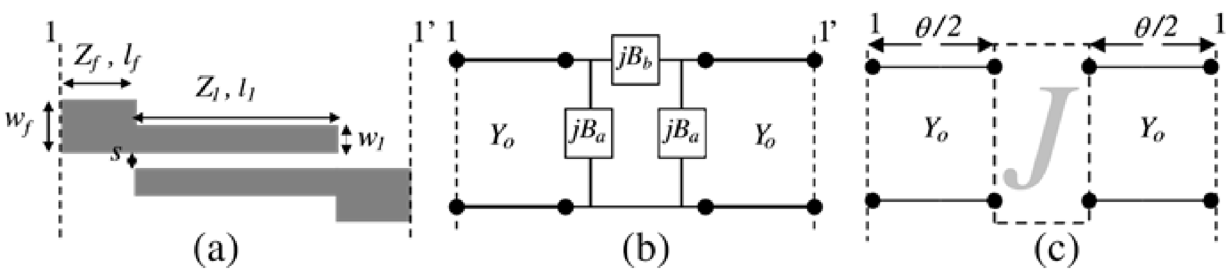


Figure 4 (a) Single-stage of the PCML-SIR structure, (b) Equivalent circuit for reciprocal two-port network admittance for lossless PCML-SIR structure, (c) Equivalent J-inverter network with susceptance J of the PCML-SIR structure.

$$Y_{11} = Y_{22} = \frac{-j}{2}\left[\frac{1}{Z_{even}} cot\beta_{even} l_{even} + \frac{1}{Z_{odd}}\ cot\beta_{odd} l_{odd}\right] \qquad (7)$$

$$Y_{12} = Y_{21} = \frac{-j}{2}\left[\frac{-1}{Z_{even}} csc\beta_{even} l_{even} + \frac{1}{Z_{odd}}\ csc\beta_{odd} l_{odd}\right] \qquad (8)$$

$$\frac{Z_{odd}}{Z_{even}} = \frac{\sin(\beta_{odd} l_{odd})}{\sin(\beta_{even} l_{even})} \tag{9}$$

The electrical coupling coefficient of the neighbouring coupled parallel lines is given in Equation (10).

$$k = \frac{f_2^2 - f_1^2}{f_2^2 + f_1^2} \tag{10}$$

Where f_2 and f_1 are the even and odd resonant frequencies of the PCML-SIR resonator, respectively.

3. The Simulation of the Proposed PCML-SIR Structure Filter

The combination of SIR and PCML is shown in Figure 5. This structure is suitable for the design of the microstrip filtering antenna because the higher-order resonant modes can be shifted or suppressed, and the spurious responses have been suppressed. The essential goal of using the PCML-SIR structure is to enhance the coupling PCML structure through the required passband compared with the traditional method in which they are using the dimensions of the PCML to control the coupling factor and complete design performance.

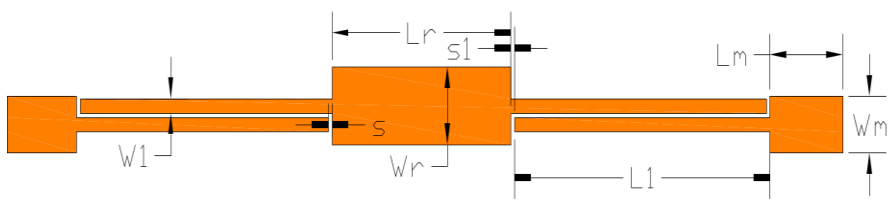


Figure 5 PCML – SIR filter structure.

Figure 6 shows the simulated S_{11} – parameters of the PCML – SIR filter over a wideband frequency range.

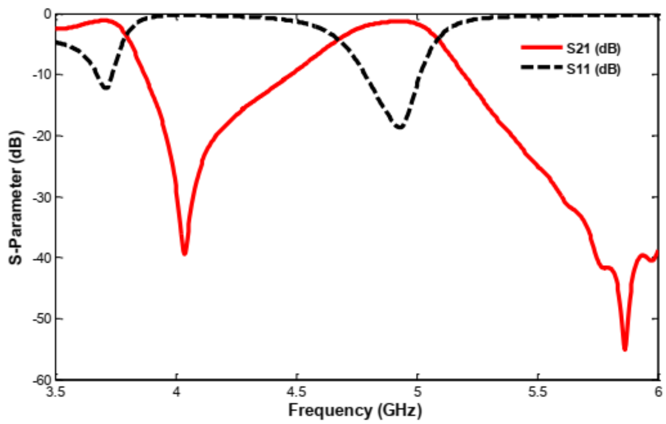
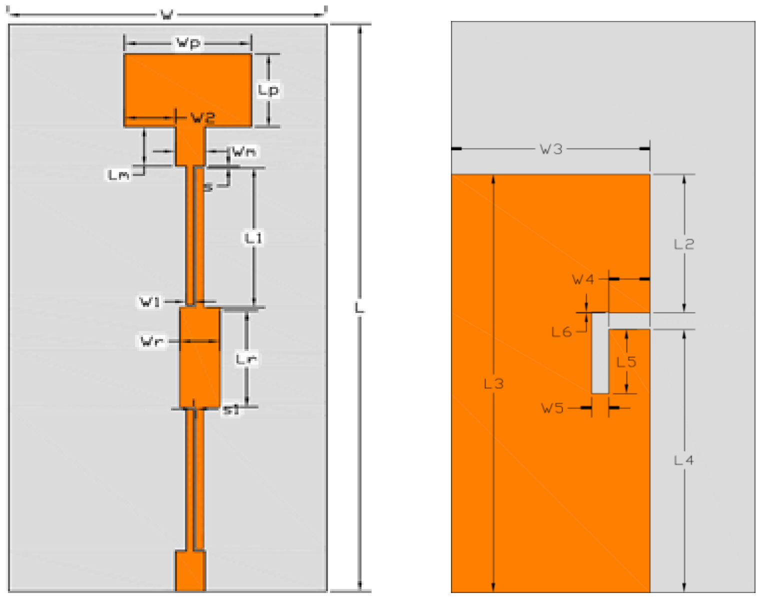


Figure 6 Simulated S – parameter of the PCML – SIR

4. The Proposed Filtering Antenna Design

The circuit design of the proposed filtering antenna structure is shown in Figure 7. The strip and slot widths of the PCML-SIR structure are adjusted to achieve a filtering process in the passband at the center frequency f_o =5.76 GHz. The integration of the PCML – SIR filter and the (MPA) changes the characteristics of both the filter and the antenna. However, the filter has a wide-band frequency range, the integration process is already suppressed out unwanted spurious responses and shifted the center frequency from 5.2 GHz to 5.76 GHz; on the other hand, the bandwidth of the antenna has increased and improved the design performance compared with the conventional patch antenna.



(a) Top view. **(b) Bottom view.**

Figure 7 The layout of the proposed microstrip filtering antenna design.

The filtering antenna structure is achieved on a dielectric substrate material, which has a dielectric constant $\epsilon_r = 2.2$ (Rogers RT 5880), and loss tangent $tan\delta = 0.009$ with a dielectric substrate thickness, $h = 1.572$. The filtering antenna circuit is fed through a 50 Ω microstrip feed line. The optimized dimensions of the proposed filtering antenna design are given in Tables 2 and 3.

Table2 The optimized dimensions of the top-view of the filtering antenna design circuit.

W (mm)	**Wp (mm)**	**Wm (mm)**	**W_1 (mm)**	**W_2 (mm)**	**Wr (mm)**	**S (mm)**
26	10.35	2.41	0.6	4.15	3.3	0.06
L (mm)	Lp (mm)	Lm (mm)	L_1 (mm)	Lr (mm)	S_1 (mm)	
56	7.17	3.83	13.8	9.8	0.1	

Table 3 The optimized dimensions of the bottom – view of the filtering antenna design.

W_3 (mm)	**W_4 (mm)**	**W_5 (mm)**	**W_6 (mm)**
17	3.4	1.5	13.6
L_3 (mm)	L_4 (mm)	L_5 (mm)	L_6 (mm)
41	25.8	6.3	0.1

5. Simulation and Discussion:

Based on the above study, the achievement of the proposed filtering antenna design shown in Figure 7 is designed and optimized by using Computer Simulation Technology (CST) software. Figure 8 shows the simulated S_{11} – Parameter and gain of the proposed filtering antenna design for optimized coupling spacing distance (S). Changing the coupling spacing distance (S) affects both bandwidth and the circuit specifications such as return loss and frequency as illustrated in Figure 9. The relationship of the coupling coefficient *k* with the coupling spacing S is shown in Figure 10, and the relationship of the center frequency of the proposed PCML-SIR filtering antenna design with the coupling space (S) is illustrated in Figure 11. As shown in Figure 11, the center frequency decreases with the increase of the coupling space (S). The design parameters of the proposed filtering antenna show good design specifications compared to conventional patch antenna in the same environment, as shown in Figure 12. The comparison of the design parameters between the proposed filtering antenna design and the traditional patch antenna design is listed in Table 4.

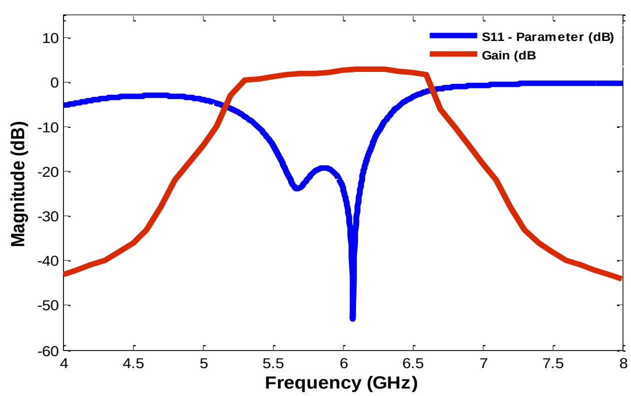


Figure 8 Simulated S_{11} - Parameter gain of the optimized filtering antenna design.

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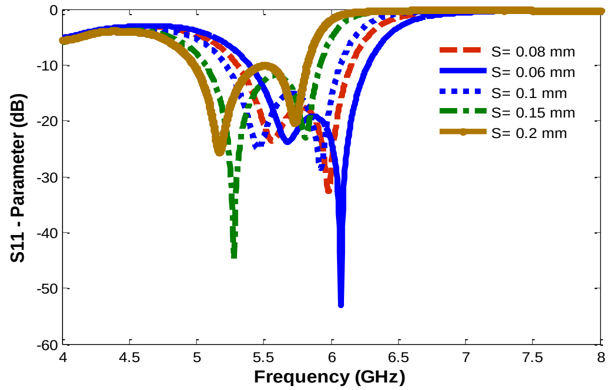


Figure 9 The simulated S_{11}-parameter of the filtering antenna for various coupling spacing distances (S).

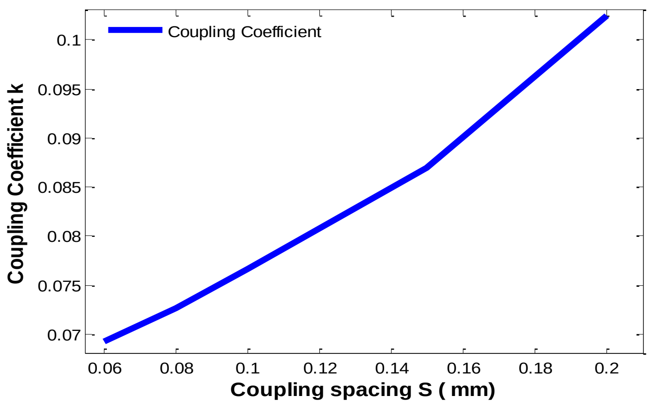


Figure 10 The curve of the coupling coefficient changes with the coupling spacing S.

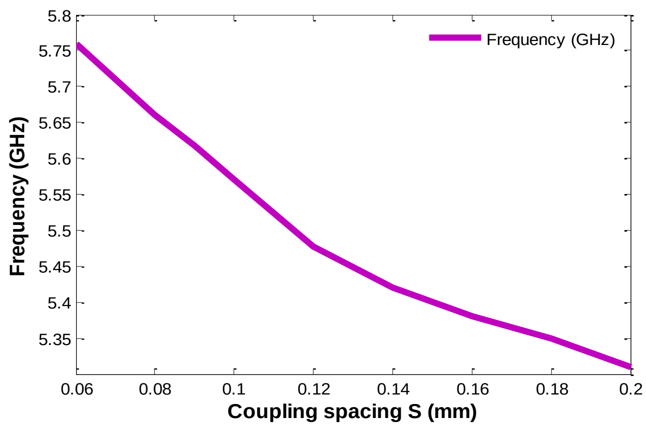


Figure 11 The curve of the center frequency changes with the coupling spacing S.

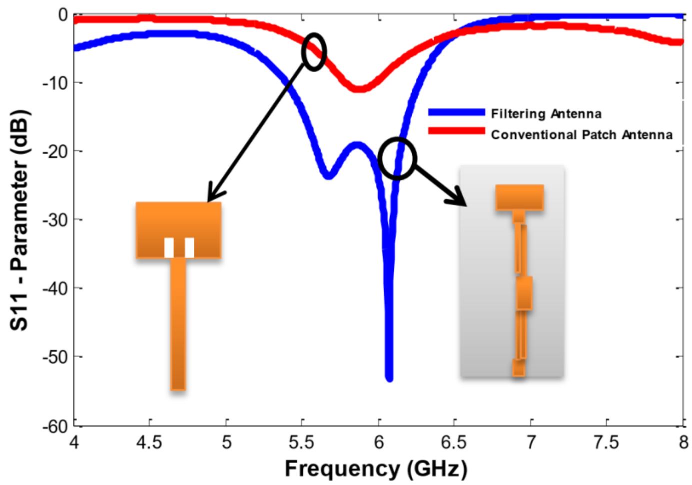


Figure 12 The simulated S_{11}-parameter of the filtering antenna and the rectangular patch

Table 4 Comparison of the design parameters between the filtering antenna and

Parameter	The filtering antenna	The patch antenna
Centre Frequency (f_o)	5.76	5.92
Return Loss (dB)	-19	-11.7
Gain (dB)	2.88	1.418
Fractional Bandwidth (FBW)	20 %	14.7 %
Radiation Efficiency	71.67	53.83

Figure 13 shows the 3D view of the far-field radiation pattern of the proposed PCML-SIR filtering antenna, and Figure 14 shows the simulation far-field of E-field and H-field respectively.

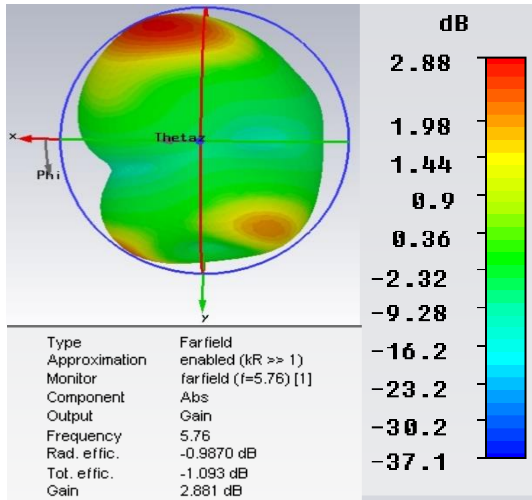
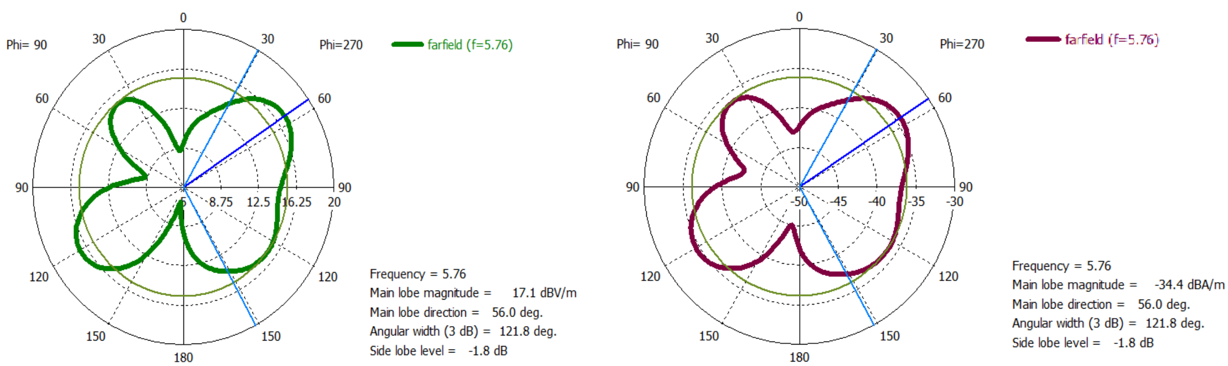


Figure 13 Simulated results of the 3D far-field radiation pattern of the filtering antenna at 5.76 GHz.



(a) (b

Figure 14 Simulated far-field (a) E-field (b) H-field

The effect of the slits technique loaded on the structure of the ground plane was proposed to enhance the passband bandwidth and improve the performance of the overall circuit design [12]. Figure 15 shows the S_{11}-parameter of the proposed PCML-SIR filtering antenna design with and without slits. The comparison of this work and other work references is listed in Table 5.

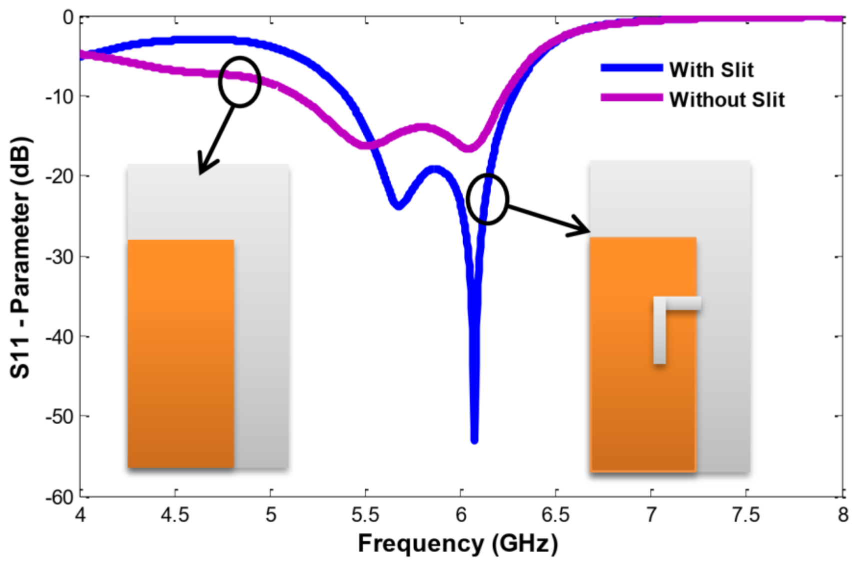


Figure 15 The S_{11} – parameter of the proposed filtering antenna with and

Table 5 Comparison of the design parameters of this work and other work references.

Design Parameters	Other Work references		This Work
	Ref. [13]	Ref. [14]	
Operating frequency (fo) GHz	5.29	5.5	5.76
Fractional bandwidth (FBW)	8.20%	12.33%	20%
Circuit size	28 ×18.285 mm^2	42.6×42.6 mm^2	26× 56 mm^2
Gain (dB)	2.5	1.89	2.88
Return loss (dB)	-15	-10	-19

6. Conclusion

The design of a wideband microstrip filtering antenna has been presented in this article. The main goal of this design is to use it for high-speed data rate transmission applications. The idea is based on the integration of a microstrip parallel-coupled microstrip lines stepped impedance resonator filter, and a monopole patch antenna. The integration process has improved the performance of the design specifications compared to the conventional patch antenna in the same design environment. The simulation results of the proposed filtering antenna circuit have been taken at different values of the coupling spacing (S). From the design results, it is clear that the best specifications of the proposed filtering antenna circuit took place at S = 0.06 mm. The effect of the slits technique loaded to the ground plane was proposed to enhance the bandwidth and improve the performance of the overall circuit design. The proposed filtering antenna design circuit shows a good improvement in bandwidth, gain, and radiation efficiency. Also, it has an acceptance selectivity and low loss in an operating passband and high spurious response suppression in the stopband.

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تصميم هوائي ترشيح شريط دقيق جديد واسع النطاق باستخدام تقنية PCML-SIR

الخلاصة: *تقترح هذه المقالة بنية تصميم جديدة لهوائي ترشيح microstrip عريض النطاق. يعتمد هيكل تصميم هوائي الترشيح Microstrip على دمج مرشح مرنان المعاوقة المتدرجة الخطية المتوازية (PCML - SIR) مع هوائي رقعة أحادي القطب. هوائي الترشيح المقترح مناسب لتطبيقات إرسال معدل البيانات عالي السرعة ، والتي لها تردد مركزي (fo = 5.7) جيجا هرتز. لتصميم الهيكل المخطط له عرض نطاق جزئي (FBW) يبلغ حوالي 20٪. هذا التصميم له خسارة عودة (RL = -19 ديسيبل) والكسب على تردد نطاق التمرير يساوي (2.88 ديسيبل). لهوائي الترشيح المصغر المقترح كفاءة إشعاع جيدة تبلغ حوالي (71.67 %). يحتوي هذا التصميم على مستوى أرضي غير مكتمل وشق عكسي على شكل حرف L محمل. تم محاكاة تصميم هوائي الترشيح المقترح باستخدام برنامج CST (Studio Suite Technology Simulation Technology). يُظهر هذا التصميم توافقًا جيدًا بين مرشح PCML-SIR وهوائي الرقعة أحادي القطب. تظهر نتائج تصميم المحاكاة خسارة منخفضة في نطاق المرور والقمع العالي للاستجابات الزائفة في نطاق المنع. الهدف الرئيسي لتصميم PCML-SIR هو استخدامه لنقل البيانات عالي السرعة الذي يحتاج إلى نطاق ترددي عريض.*